# THE INTERSTELLAR PROBE: A FRONTIER MISSION TO THE HELIOSPHERIC BOUNDARY AND INTERSTELLAR SPACE

T.E. Holzer[a], R.A. Mewaldt[b], and M. Neugebauer[c]

a) NCAR/HAO, Boulder, CO 80307 USA
b) California Institute of Technology, Pasadena, CA 91125 USA
c) Jet Propulsion Laboratory, Pasadena CA 91109 USA

**Abstract:** The Interstellar Probe mission would be designed to cross the solar wind termination shock and heliopause and make a significant penetration into interstellar space, thereby providing the first comprehensive *in situ* studies of the plasma, energetic particles, cosmic rays, fields, gas, and dust in the nearby Galaxy. We report on the scientific rationale and requirements for this mission, including its unique opportunities for cosmic ray studies.

**1. Introduction:** In our present view of the large scale structure of the heliosphere (see Fig. 1), the solar wind flows radially outward to a "termination shock," surrounded at somewhat greater distance by the heliopause, the boundary between solar-wind and interstellar plasmas. A bubble of solar wind thereby shields the inner heliosphere from the plasma, energetic charged particles, and fields of the interstellar medium (ISM); to observe these directly one must get outside the heliopause. Although the size of the heliosphere is uncertain, present estimates place the termination shock and nose of the heliopause ~100 to 150 AU from the Sun.

In March, 1990 NASA's Space Physics Division sponsored a workshop to study the scientific rationale, measurement objectives, and instrumentation requirements for an Interstellar Probe Mission, whose primary objectives would be *in situ* particles and fields measurements at the boundary of the heliosphere and in local interstellar space. We summarize the results of the Interstellar Probe Workshop (IPW); see also the workshop report[1] and Space Physics Strategy/Implementation Study[2].

**2. Rationale and Scientific Objectives:** The objectives of Interstellar Probe would be be to: 1) Explore the nature of the ISM and its implications for the origin and evolution of matter in the Galaxy: 2) Explore the structure of the heliosphere, and its interaction with the ISM; and 3) Explore fundamental astrophysical processes in the heliosphere and ISM. Among the wide range of fundamental issues that Interstellar Probe would address are several that are critical to cosmic ray physics; including:

- *In situ* observations would investigate acceleration of the anomalous cosmic rays and other particles at the solar wind termination shock.

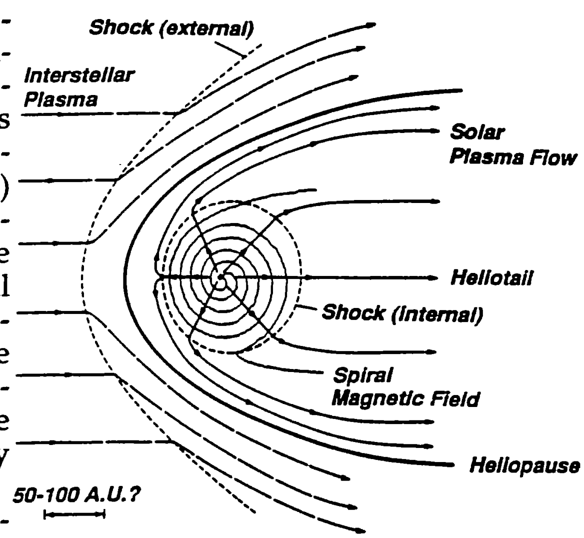



Fig. 1: Schematic illustration of a plausible structure for the heliosphere.

• Direct measurements of unmodulated cosmic ray spectra, of interstellar plasma, and of the magnetic field would delineate the pressure and energy balance in the local ISM, and assess the degree of cosmic ray heating of interstellar gas. As indicated in Fig. 2, a wide range of low energy interstellar spectra are compatible with measurements at 1 AU.

• Electron/positron measurements would determine parameters critical to diffuse gamma-ray production, including the 0.511 MeV line.

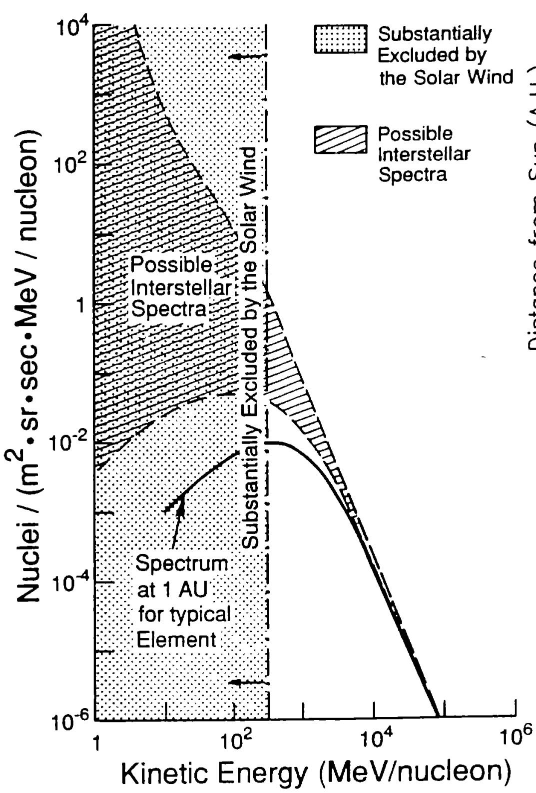
• Direct measurements of elemental/isotopic abundances from H to Fe in the interstellar gas and in low energy cosmic rays would provide crucial information for studies of the chemical evolution of the Galaxy.

• Cosmic ray contributions to Galactic Li, Be, and B abundances, and to cosmologically important isotopes $^2H$, $^3He$, and $^7Li$ could be assessed.

• *In situ* particle and field studies would discriminate between models of cosmic ray acceleration and transport in the Galaxy, and acceleration and solar modulation processes in the heliosphere.

**3. Trajectory Considerations:** To accomplish its objectives Interstellar Probe should acquire data to at least ~200 AU. Allowing for a 25 year mission and possible trajectory maneuvers an escape velocity of ~10 AU/year is required (see Fig. 3). The trajectory should be generally towards the nose of the heliosphere, the ram direction of the inflowing interstellar gas.

One approach for achieving the required spacecraft velocity follows a trajectory that includes a Jupiter swingby, followed by a pass within ~4 solar radii where an impulsive $\Delta V$ maneuver is performed. JPL studies have achieved escape velocities of ~10 AU/year with trajectories that combine a powered solar flyby with planetary gravity assists. Significantly greater



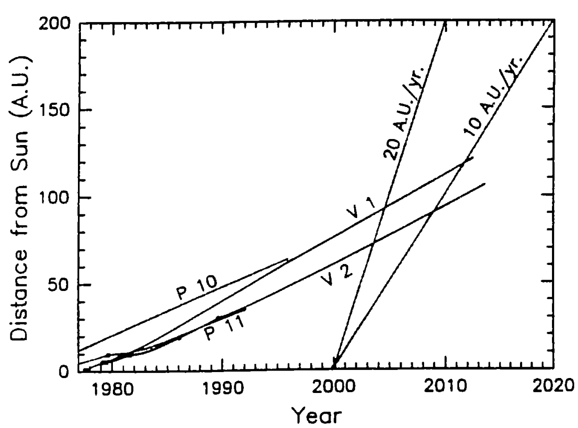




Fig. 3: (above) Heliospheric distances reached by Pioneer, Voyager, and Interstellar Probes launched in 2000 at 10 and 20 AU/yr.

Fig. 2: (left) Cosmic ray spectrum for a typical element illustrating that low energy interstellar particles are excluded from the heliosphere.

velocities might be achieved by advanced propulsion systems such as a solar sail, or by nuclear thermal or nuclear electric propulsion systems developed for the Space Exploration Initiative[3].

**4. Instrument Requirements:** The IPW identified a strawman payload of 13 instruments (requiring ~120 kg and 100 W.) to address the objectives described above. Table 1 compares these instruments, almost all based on existing technology, with those on Voyager. It is possible that one or more of the Voyager or Pioneer spacecraft may locate the termination shock and provide valuable exploratory data within their lifetimes. Interstellar Probe

**Table 1: Comparison of Voyager and Interstellar Probe Capabilities**

| | Voyagers | Interstellar Probe | Comments |
|---|---|---|---|
| Maximum distance | 130 AU (V1)<br>107 AU (V2) | ≥200 AU | |
| Spacecraft speed | 3.5 AU/y | ≥10 AU/y | |
| Spacecraft orientation | 3-axis stabilized | Spinning | Provides 3-D coverage for many studies |
| Data rate | 46.6 bps at 100 AU when tracked | 300 bps at 200 AU continuous | Higher data rates possible closer to Earth |
| <u>Measurement capabilities</u> | | | |
| Magnetic fields | Yes | Yes | Expected IP and IS fields within existing capabilities |
| Plasma waves: | | | |
| Electric fields | Yes | Yes | Both E & M required to |
| Magnetic fields | No | Yes | identify wave modes |
| Distant Solar wind: | | | |
| Protons | to 107 AU | Yes | 3-D dynamics/composition |
| Alphas | to 60 AU | Yes | of distant solar wind and |
| Electrons | to 5 AU | Yes | sub-sonic post-shock plasma |
| Interstellar pickup ions | No | Yes | Composition and dynamics |
| Interstellar plasma: | | | |
| Density, veloc., temp. | No | Yes | 3-D dynamics/composition |
| Elemental/isotopic comp. | No | Yes | for $1 \leq Z \leq 28$ and $1 \leq A \leq 60$ |
| Charge states | No | Yes | with excellent resolution |
| Suprathermal particles: | | | |
| Protons, alphas, electrons | Yes | Yes | Spectra of elements ($Z \leq 8$) & |
| Elemental composition | No | Yes | element groups to Z=26 from |
| Charge states | No | Yes | 20 keV/nuc to a few MeV/nuc |
| Anom./Galactic cosmic rays: | | | |
| Element energy spectra | Yes | Yes | Z = 1 to 30 over energies |
| Isotopic composition | $Z \leq 14$ | Yes | from ~10 to 500 MeV/nuc |
| Electrons | Yes | Yes | Electrons from 1 to 5000 MeV |
| Positrons | No | Yes | Positrons from 1 to 100 MeV |
| Interstellar neutrals | No | Yes | Heavy element composition will need new developments |
| Dust | No | Yes | Sensitivity to grains $>10^{15}$g; composition studies possible |
| Gamma-ray bursts | No | Yes | Long baseline triangulation |
| UV flux | to 76 AU | Yes | Column densities of IS H, He |
| IR flux | No | Yes | 1° sky maps to identify comets and dust |

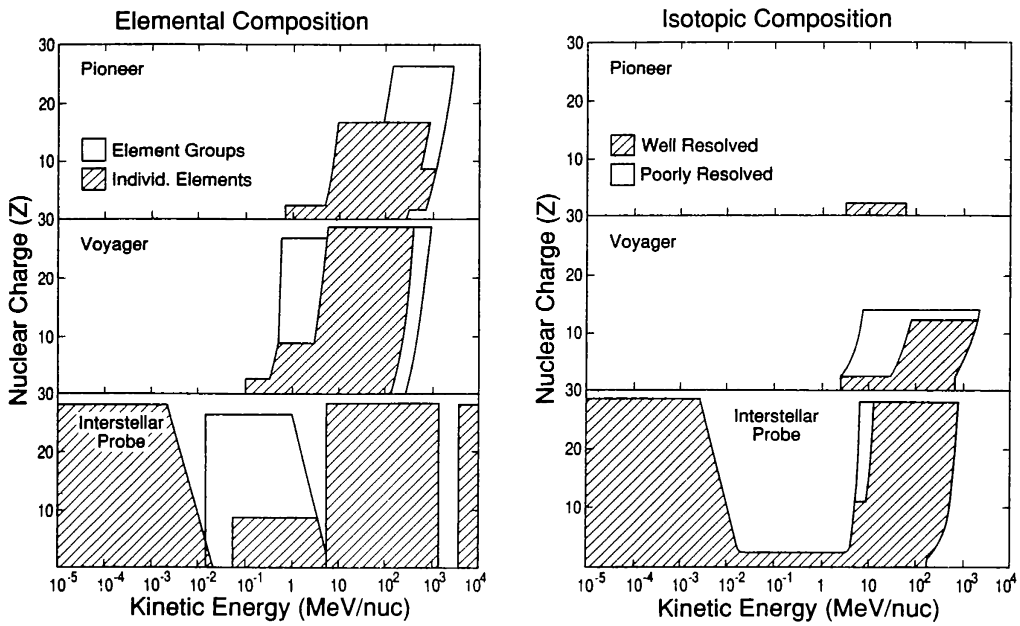



Fig. 4: Capability for measuring elemental/isotopic abundances by instruments on Pioneer, Voyager, and Interstellar Probe.

would greatly extend these pioneering ventures by providing detailed, comprehensive measurements with modern instrumentation specifically designed to observe the boundary of the heliosphere and the ISM itself. Fig. 4 illustrates the progressive capability for studying the composition of interstellar plasma and cosmic rays; such dramatic advances are also possible for other instruments[1]. It is important to identify any additional instruments that could make fundamental contributions to this mission.

**5. Summary:** The Interstellar Probe is presently included in the NASA Space Physics Division plan for the years beyond 2000[2]. In view of the fundamental contributions that this mission would make to studies that include space plasma physics, nucleosynthesis, stellar and galactic evolution, astrophysics, and cosmology, it is important that NASA continue to develop the required technology, and that possible international interest in this truly exploratory mission be investigated.

**Acknowledgements:** We are grateful to NASA's Space Physics Division for supporting this study and to the participants in the Interstellar Probe Workshop for their enthusiastic hard work and valuable contributions.

## References

1) The Interstellar Probe: Scientific Objectives and Requirements for a Frontier Mission to the Heliospheric Boundary and Interstellar Space. T. E. Holzer, R. A. Mewaldt, and M. Neugebauer, editors, 1990.
2) "Space Physics Strategy/Implementation Study - The NASA Space Physics Program for 1995 to 2010", Vols. 1 & 2, 1991.
3) "Report of the Synthesis Group on America's Space Exploration Initiative" T. P. Stafford, Chairman (1991).